6. Slips of the Pen, Tongue, and Typewriter: A Contrastive Analysis

This article reviews available data on spontaneous and evoked slips of the pen, tongue, and typewriter, and concludes that slips of the pen and typewriter exhibit different regularities from slips of the tongue and reflect different constraints on production. The comparison of these three classes of slips also clarifies some of the similarities and differences in the processes underlying speech, writing and typewriting.

1. Introduction

Speaking, writing, and typing are the main output modalities for expressing language among literate adults. However, speech has received far more scientific attention than typing and writing, and for good reasons. Typing and writing are relatively rare skills that have been recently acquired in our evolutionary history (Ellis 1988 b): No universal genetically-based processes have evolved specifically to represent writing and typing, unlike speech. If acquired at all, lexical and sublexical spelling processes are acquired after language, and are grafted onto semantic and syntactic processes for speech. As a result, patients with high level semantic or syntactic speech impairment invariably exhibit the same impairment in writing and typing (Ellis 1988 b). Finally, because different cultures have invented radically different systems for writing and typing, we cannot be sure *a priori* that orthographic processes do not differ for languages with fundamentally different graphic systems (Ellis 1986 b).

For studying some issues, however, typing offers major advantages over speech. The effect of skill on errors is one such issue: Degree of typing skill can be manipulated in ways not possible for speech. Input stimuli in studies of transcription typing can also be manipulated in ways not possible for speech. With typists instructed to type exactly what appears on a video display, a computer can replace an upcoming letter with another, different letter at some unpredictable time prior to typing. The time when such a change causes errors or disrupts timing indicates when control has passed from input transcription to keystroke execution (Salthouse 1984; 1985; 1986). Finally, typing errors offer technological advantages over speech errors for issues related to timing. Even the best techniques for inducing speech errors cannot measure time of output with the ease and precision routinely possible for computer analyzed keystrokes.

2. Errors: General Considerations

2.1. Units of Analysis in Writing and Typing

Three hierarchically related units of analysis have proven useful in studies of writing and typing: graphemes, allographs, and graphic motor patterns (Ellis 1979). 'Graphemes' correspond to letters of the alphabet, and can be expressed in three ways: as a keystroke in typing, as a letter in writing, or as a letter name in spelling words aloud (Ellis 1988 a). 'Allographs' are the various forms or variants of a grapheme that are accepted within a writing community, e. g., upper vs. lower case, and printed vs. cursive (Pulgram 1951; Gelb 1963). 'Graphic motor patterns' are particular sequences of muscle movements for expressing an allograph and may be unique to a given individual or context of use (van Galen 1980). The main focus of research has been whether graphic motor patterns succeed in depressing their key in typing and how they unfold in handwriting, i. e., the strokes composing a letter, their sequence, direction, relative size, position on a page, relative position on a line, and the muscles involved, e. g., finger muscles for horizontal surfaces and arm muscles for vertical surfaces (van Galen/Smyth/Meulenbroek/Hylkema 1989).

2.2. Errors: Definitional Issues

By general convention, errors are only recorded when the correct form is known and intended: The correct sequence of phonemic or graphemic components exists in memory, but the wrong components are inadvertently activated. This s i n e q u a n o n aside, the definition of 'error' differs in subtle and largely unacknowledged ways in studies of tongue (cf. art. 5), pen and typing slips. By generally accepted definition, a typing error occurs when an inapproppriate key is depressed sufficiently to allow electrical contact. A key hit hard or long enough to cause repeated electrical contact therefore constitutes an error, and so does an accurate keystroke that is too weak to make electrical contact (Grudin 1983). However, analogous events have never been counted as pen or tongue slips. Collections of pen and tongue slips do not include locally faint, indistinct and awkward penstrokes, or faint, slurred and overly loud speech sounds.

The unique definition of typing error has contributed other, perhaps artificial differences between slips in the three output modalities. For example, most pen and tongue slips involve whole letters or speech sounds (Ellis 1979), but some can only be described as involving subcomponents of a speech sound (Fromkin 1973) or letter (Ellis 1979; 1988 a), e. g., the upstroke for *d* in the anticipatory pen slip, *made* → *mdde*. (Present examples are realistic, but invented, and the arrow in such formuli stands for 'could have been misproduced as'). Although all acts of speaking, writing, and typing can be described as involving a hierarchic organization of such components and subcomponents (MacKay 1987), typing slips can only involve whole letters or keystrokes by prior definition.

2.3. Organization of the Present Chapter

I first describe typing errors, then pen slips: their categories, temporal characteristics, and relation to variables such as experience, and graphemic, allographic, and motoric factors. Error detection and the role of different types of feedback are discussed next. Finally, I examine similarities, differences and gaps in existing research comparing errors in speech, writing and typing.

3. Typing Errors

3.1. Categories of Typing Errors

Studies of typing typically analyze errors into five main categories discussed below.

3.1.1. Substitution Errors in Typing

Videotapes of expert typists indicate that substitution errors (e.g., *type* → *typr*) usually involve adjacent keys, and result from a stroke with the wrong finger to the wrong key rather than from an inappropriate execution or movement trajectory with the correct finger (Grudin 1983). Whole word substitutions also occur (e. g., *perhaps* → *maybe*), but reflect misrepresentation of the input string rather than genuine errors.

The most interesting class of substitution errors, known as homologous intrusions (e.g., *type* → *tyqe*), involves substitution of the mirror-image or anatomically homologous finger and keyboard position on the opposite hand, a phenomenon that exceeds chance expectation (Book 1925; Grudin 1983 a; Munhall/Ostry 1983; Wells 1916). Under the usual interpretation, homologous intrusions result when a keystroke has been specified for the appropriate finger and key, but for the wrong hand (Salthouse 1986). However, studies of experimentally induced homologous intrusions in keying tasks that resemble typing suggest an alternative to this hand misspecification hypothesis. Under this priming hypothesis (MacKay 1971), units representing movements of anatomically homologous fingers are interconnected via the corpus callosum and prime one another prior to activation and actual movement. The priming hypothesis explains the built-in coordination of homologous fingers, and why tasks requiring simultaneous tapping with homologous fingers are performed especially rapidly and accurately. The priming hypothesis is also more general than the hand misspecification hypothesis, explaining additional phenomena such as why fewer homologous intrusions occur in the dominant hand (e. g., the right hand in right-handed subjects), and why instructions to 'pay attention to' one hand reduce the number of homologous intrusions in the attended relative to unattended hand (MacKay 1971). Finally, under the priming hypothesis, homologous intrusions represent a finger movement analog of speech errors known as blends (e.g., *sotally*, a blend of *solely* and *totally*; and *me together*, a blend of *me too*, and *we're together*; MacKay 1973).

3.1.2. Intrusion Errors in Typing

Extremely short interkey intervals follow intrusions (e. g., *type* → *tyupe*), which usually result from imprecise keystrokes: the appropriate finger strikes two keys together or hits a key in passing (Grudin 1983). Repetition intrusions (e. g., *type* → *tyype*) reflect either keyboard bounce or inadequate deactivation of a keystroke (Grudin 1983).

3.1.3. Omission Errors in Typing

Omission errors (e.g., *type* → *tpe*) usually result from strokes that are too weak to fully depress difficult-to-reach keys (e.g., q, b), and usually fall within keystroke intervals about twice the normal duration (Shaffer 1975). Medial letters of a word are more likely to be omitted than initial letters, a phenomenon observed originally in speech errors (MacKay 1969). Interestingly, some keystroke omissions seem to occur because the same letter or type of stroke was recently typed (e.g., *artificial* → *artifical*), as if an inhibitory process follows activation of underlying units, making repetition difficult (Grudin 1983; MacNeilage 1964). This too was observed originally in speech errors (MacKay 1987) and only very recently and elegantly in writing errors (van Galen 1990).

3.1.4. Transposition Errors in Typing

Most transpositions (e.g., *type* → *ytpe*) are cross-hand rather than within-hand, both absolutely and relative to chance, as if a preprogrammed letter upcoming on the other hand is ready to strike its key too early (Salthouse 1984; 1985; 1986). More than this is probably involved, however, because interstroke intervals are virtually identical for correctly sequenced vs. transposed letters: One of the transposed letters does not come especially early and the other especially late (Shaffer 1975; Grudin 1981; 1982). Rather, transposed keys change places in time and sequence, not unlike transposed sounds in speech errors such as *passification* → *fassipication* (MacKay, 1987).

3.1.5. Other Classes of Typing Errors

Four less frequent classes of typing error are migrations (e.g., *type* → *ptye*), anticipations (e.g., *type* → *etype*), misdoublings (e.g., *free* → *frre*), and alternations (e.g., *these* → *thses*). However, anticipations of nearby letters, as in *type* → *tpype*, are often counted as intrusions or transpositions, and indeed are indistinguishable from transpositions such as *type* → *tpye* if the typist has attempted to minimize the anticipation error (here, *tpype*) by not repeating *p* in its normal spot. Misdoublings such as *trre* (for *tree*) suggest that double letters are stored as a single letter together with a repeat tag that can become attached in error to the wrong letter (Lashley 1951). Alternations such as *thses* (for *these*) likewise suggest that alternating letters (here, the *e* in *ese*) are stored with an alternation tag that can become attached in error to the embedded letter (here, *s*).

3.2. Experience, Frequency and Typing Slips

Both experience (hours of typing over the course of a lifetime) and relative frequency (how often a given key is struck relative to all others) influence typing errors. Experience increases the proportion of across-hand vs. within-hand transpositions (Grudin 1983), perhaps because a single, hierarchically organized unit represents within-hand digrams (letter pairs) in expert typists. Experience also reduces the relative proportion of substitutions and homologous intrusions, which virtually disappear with high levels of typing skill (Grudin 1983). Finally, relative frequency also influences substitutions, which usually result in higher frequency digrams than correct or intended digrams (Grudin 1983).

3.3. Timing and Typing Errors

Because errors in typing, writing, speech, and other skills increase with speed or overall rate of output (MacKay 1982), it becomes an interesting question whether errors reflect 'local haste', a short-term burst in speed prior to the error. Timing characteristics of keystrokes before and after errors link some but not all types of error to local haste (Grudin 1981; 1983). Keystroke intervals immediately preceding omissions and transpositions are usually shorter than average, as if typists make these errors when attempting to perform faster than accuracy permits. However, interstroke intervals preceding substitutions and intrusions provide no corresponding evidence of local haste.

4. Classes of Pen Slips

Pen slips typically fall into four classes, discussed below, but over 10% allow dual classification, e.g., combined anticipation and perseveration (van Nes 1971). Transpositions (e.g., *results* → *resulst*) are a fifth, but quite infrequent type of writing error (van Nes 1971).

4.1. Anticipation Errors in Writing

Anticipations (e.g., *Writing* → *Triting*) represent the most frequent category of writing errors, comprising over 40% of most collections (van Nes 1971). As in speech, components within and between words are anticipated, often with contextual accommodation, as in *MacKay* → *MakcKay* and *Writing* → *Triting*, where the anticipated t becomes capitalized (T) to match the case of the W intended for that position (Ellis 1979; 1988 a; 1988 b). Such accommodations suggest that graphemes rather than allographs or graphic motor units are anticipated, followed by choice between upper vs. lower case at the allographic level (Ellis 1979). Also counted as anticipations are 'switches' where a writer starts to write one letter but switches at a point of similarity to an upcoming letter (e. g., *made* → *mdde*). Because switches always involve strokes or subcomponents of a letter, they can be said to occur during execution of graphic motor patterns (Ellis 1988 b).

4.2. Perseveration Errors in Writing

Perseveration errors are much less frequent than anticipations, comprising about 10% of most collections, and result from reactivation of a recently activated grapheme or graphic motor unit, as in stroke additions such as *n* → *m* (van Nes 1971).

4.3. Omission Errors in Writing

Dropping one or more strokes within a letter (e. g., *m* → *n*; *g* → *a*) is an interesting type of omission error. Another is letter masking (Ellis 1979), omission of a letter just written (e. g., *writing* → *writng*) or about to be written (e. g., *writing* → *wrting*). Letter masking may involve allographic units because masking followed by case accommodation (e. g., *Tutors* → *Tuors*) has never been observed (Ellis 1979).

5. Error Detection

Skilled typists normally detect from 50% to 70% of their typing errors, and as with speech errors, detect them very quickly: With instructions to stop typing after making an error, only one keystroke usually follows the error (Long 1976; Shaffer/Hardwick 1969). Indeed, typists detect some errors before they fully execute them because incorrect keys are often pressed more lightly than normal (Rabbitt 1978; Wells 1916). The interval following an error is longer than average, and exceeds intervals two or more keystrokes before or after the error, as if errors are registered at some level before normal typing is resumed (e. g., Salthouse 1984; 1985; 1986). Post-error pauses follow the second stroke of transpositions, as if both strokes are produced as a unit and detected as erroneous during the pause (Grudin 1983). Skilled typists also mistype words such as *the* without pausing or stopping (as instructed), as if these words represent multi-letter ballistic units (Grudin 1983).

6. Feedback in Handwriting and Typing

A visually based engram must play a role in detecting some typing errors because typists tend to detect about 30% fewer errors when prevented from seeing their typed copy (Long 1976; Rabbitt 1978; West 1967). However, only relatively unskilled typists exhibit this pattern: highly skilled touch typists generate comparable speed and accuracy whether they can see their copy or not (West 1967). Nonetheless, skilled typists occasionally glance at the keyboard to hit relatively unfamiliar keys (e. g.,], $, %, +, @, #, ^, &, *, {, <, 1 – 10), and to ensure that their fingers occupy home-row position (Cooper 1983). Visual feedback also plays a role in pen slips because eliminating visual feedback increases both errors (Smyth/Silvers 1987) and writing time, especially for repeated letters and strokes, as in *m*, *n*, *w* (van Galen/Smyth/Meulenbroek/Hylkema 1989).

The auditory feedback accompanying keystrokes is also related to typing errors because unskilled typists make more errors when this auditory feedback is delayed (Long 1976; 1976; Cooper 1983). Introducing an extraneous tone also disrupts subsequent taps in tasks resembling typing (Wing 1978).

7. Comparisons of Slips across Modalities

Because speech, typing and handwriting have been studied in virtual isolation in the past, comparisons of tongue, pen, and typing slips are virtually nonexistant. Even comparisons of errors involving tongue vs. ear in speech, and eye vs. hand in typing are rare, despite their importance for theories of error detection (MacKay 1987).

Preliminary comparisons suggest many differences between tongue, pen, and typing slips, despite the commonalities emphasized in preceding sections. Some of these skill-specific error characteristics reflect fundamental differences in how speech, typing and writing are coded and sequenced, while others are superficial, or follow from general principles.

7.1. Code and Processing Differences

Fundamental skill-specific differences in error patterns (for slips of the tongue cf. art. 5) arise from the fact that typing/writing employs a visual-spatial code (in addition to an initial phonological code; see van Nes 1985; van Galen 1990; and even Kao/Hoosain 1984) and this visual-spatial code is sequenced linearly rather than hierarchically. However, only a hierarchic rather than linear code is used in speech. For example, the *aba* in the word *abacus* is coded as two different syllables (a + ba) in speech, rather than as a linear string of phonemes. Other syllabic characteristics are also coded in speech, so that vowels can only substitute with other vowels, and syllable-initial consonants can only substitute with other syllable-initial consonants, and never with syllable-final consonants or vowels (MacKay 1987). As a result, analogs of typing errors such as alternations, e.g., *abacus* → *babcus*, do not occur in speech: Because of syllable structure constraints, a speech error involving the *b* or *a* in *abacus* might resemble *babacus* or *ubacas*, but not *babcus*, an output with fewer syllables and a fundamentally different syllable structure from *abacus* (MacKay 1973). In typing, however, vowels often substitute with consonants (e.g., *ramp* → *rmap*), and syllable-initial consonants often substitute with syllable-final consonants (e.g., *artful* → *arftul*).

Consonant clusters, another component of syllables, also differentiate tongue vs. typing slips. Although speech errors often involve consonant clusters, e.g., *slit throat* → *thrit sloat* (Fromkin 1973), analogous typing errors have never been reported, despite diligent search (Grudin 1983). Because touch typists are assumed to develop hierarchically organized graphemic units for frequent diads (letter pairs such as *th*), the absence of multiletter sustitutions in skilled typing is curious and suggests that typing units are sequenced in very different ways from the phonological units for speech.

Because graphemic and allographic representations with visual-spatial characteristics ultimately trigger keystrokes, typing errors often violate the phonological constraints seen in speech errors. Thus, phonological similarity plays only a minor role in writing and typing errors, but a major role in speech errors: For example, segment substitutions in speech tend to involve units that differ in only a single distinctive feature (MacKay 1969). In contrast, visual-spatial similarity is a more powerful factor in pen and typing slips, and represents the more likely explanation for the well-established effects of finger movement similarity and pen stroke similarity in pen (Ellis 1979), and typing slips (Grudin 1983). However, because speech production does not employ a visual-spatial code, at least for familiar words, visual similarity plays no role in tongue slips.

Differences between errors in speech vs. typing/writing can also arise from differences between orthography vs. phonology. For example, no basis for misdoublings exists in speech, unlike typing, because, unlike repeated letters, immediately repeated phonemes are virtually nonexistent in natural languages (MacKay 1970).

7.2. Superficial Cross-Modality Differences

The technology of typing, low level motoric factors, and language-specific graphic characteristics introduce superficial differences between tongue, pen and typing slips. Design of the standard Qwerty keyboard influences currently studied typing errors, and different types of errors may be observed in future studies with technologically more advanced keyboards (e.g., the Dvorjak keyboard, where the vowels occupy the left-hand home row; and chord keyboards, where simultaneously pressing several keys generates a single letter; Gopher/Karis/Koenig 1985). Low level motoric factors such as the cross-hand vs. within-hand factor in typing errors (Grudin 1983) contribute other superficial differences, and so do language specific graphic characteristics. Unlike English, for example, correspondence between graphemes and phonemes is almost perfect in Finnish (Ellis 1982), and it will come as no surprise if Finnish typing, lacking repeated graphemes, fails to exhibit misdoublings. Nor will it come as a surprise that grapheme repetition and grapheme-phoneme correspondence factors are irrelevant for Chinese, a language without graphemes (Pulgram 1951).

7.3. Differences Due to General Principles

Some skill-specific error characteristics follow from general principles that apply to all skills. For example, the principle of speed-accuracy trade-off (MacKay 1982) can account for the relative rareness of pen slips (Ellis 1982): Handwriting proceeds much more slowly than speech and typing, so that pen slips are infrequent by general principle. The relative predominance of anticipations over transpositions among pen slips may also follow from the slowness of handwriting: Because pen slips can be detected very rapidly relative to writing speed, writers can stop after detecting the first letter of transpositions, leaving on paper something indistinguishable from an anticipatory error (van Nes 1971). As a result, anticipations may be overreported, and potential transpositions underreported among slips of the pen. Finally, words are more often left incomplete following pen than tongue or typing slips (van Nes 1971), as if writing slowness allows writers to detect an error, stop, and begin the word anew.

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7. Errors and their Relevance for Models of Language Production

1. Introduction

Research in language production must provide theories of systems for control of the real-time lexical, phonological, and phrasal organization of sentences that encode the communicative intentions of a speaker. Article 1 of this handbook outlines a family of hypotheses about the architecture of the language production process. The character of the system described there relies on a variety of evidence types. One of the most powerful is the patterning of diverse types of speech errors (cf. art. 5, for discussion of data issues and a typology of errors). We will consider how such data can be brought to bear on the analysis of language production and claims about how its component systems relate to each other.

I will use the term 'Message' (M) to refer to the proximal cause of sentence construction in the sense outlined in article 1: M is the real time representation that controls the integration of sentence form, and thus expresses the speaker's communicative intent at the time of utterance. The separation of production processes into a conceptual system for message construction and a language specific system for sentence construction is an empirical claim that the error data bears on, as does a range of related experimental find-